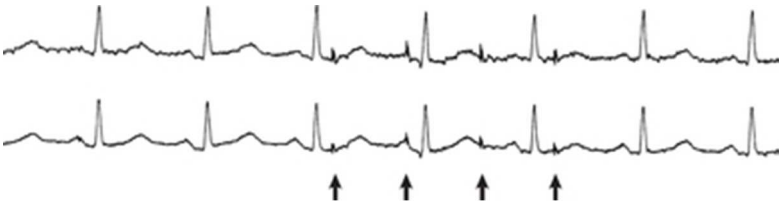

ECG leads I and II from a study subject with a central line in the internal jugular vein with an exit site at the base of the neck. The 4 arrows indicate shock artifact from 2 Hz repetitive stimulation (100 mA and 0.1 ms) delivered at the standard stimulation site of the right spinal accessory motor nerve. No changes in cardiac rhythm are detected.

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Nerve conduction studies are safe in patients with central venous catheters

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Abstract:

Introduction:

It is unknown if central venous catheters bypass the skin's electrical resistance and engender a risk of nerve conduction study-induced cardiac arrhythmia.

Objective:

To determine if nerve conduction studies affect cardiac conduction and rhythm in patients with central venous catheters.

Methods:

Under continuous 12-lead electrocardiogram monitoring, subjects with and without central venous catheters underwent a series of upper extremity nerve conduction studies. A cardiologist reviewed the electrocardiogram tracings for evidence of cardiac conduction abnormality or arrhythmia.

Results:

Ten control subjects and 10 subjects with central venous catheters underwent the nerve conduction study protocol. No malignant arrhythmias or conduction abnormalities were noted in either group.

Discussion:

Nerve conduction studies of the upper extremities, including both proximal stimulations and repetitive stimulation, do not appear to confer increased risk of cardiac conduction abnormality in those patients with central venous catheters who are not critically ill or have a prior history of arrhythmia.

Key words:

Nerve conduction studies

Central venous catheters

Arrhythmia

Electromyography

Cardiac conduction

Safety

Introduction:

The intrinsic pacing of the heart is subject to disruption by exogenous electrical current. Experimental studies suggest that as little as 200 μA of current, when applied directly to myocardial tissue, may induce a life-threatening arrhythmia.[1] The skin and pericardial soft tissues prevent this by providing substantial electrical resistance and diluting any currents that are applied to the surface of the body. In patients with intact skin, as much as 100-500 mA (milliamperes) must be applied to the body so that the circuit crosses the heart in order to induce a malignant arrhythmia.[2]

Nerve conduction studies, a component of standard electrodiagnostic testing, involve electrical stimulation of peripheral nerves. In patients with dry, intact skin, the impulses from standard nerve conduction studies cannot be detected by intracardiac sensing devices such as implantable pacemakers and defibrillators.[3-5]

Lines that breach the skin may reduce the resistance that protects the heart from stray currents. Transcutaneous pacemaker electrodes, occasionally used in critically ill patients, create a direct electrical conduit to the heart.[6] Any current applied to such a patient's body, especially in proximity to the pacemaker electrodes, would confer an enormous risk of cardiac arrhythmia. Nerve conduction studies appear to be safe in patients with peripheral intravenous lines. In a series of patients with pacemakers or defibrillators and peripheral intravenous lines, routine nerve conduction studies in the upper extremity (up to 100 mA and 0.5 ms in duration) were not detected by the sensing amplifiers in the devices and did not affect their pacing.[7] This was the case whether the intravenous line was clamped or saline was running through it.

Central venous catheters in the internal jugular or subclavian veins are commonly used for fluid resuscitation, medication administration, plasmapheresis, dialysis, and intracardiac monitoring. These catheters are larger than peripheral lines, breach the skin in close proximity to the heart, and extend towards the heart. In theory, this may bypass the large electrical sink provided by intact skin and the soft tissues of the torso. Some authors have suggested avoiding nerve conduction studies in this population, or making modifications such as stimulating contralateral to the central line and avoiding proximal stimulations. [8]

The purpose of this study was to determine if nerve conduction studies affect measures of cardiac conduction or cardiac rhythm in patients with central venous catheters.

Materials and Methods:

Subjects with central venous catheters and control subjects without intravenous lines were recruited to participate. Control subjects were recruited in the electromyography lab. All 10 of the control subjects underwent the study protocol before subjects with central lines were recruited. Patients with central lines were identified by reviewing the schedules of the inpatient dialysis and apheresis laboratories. Patients who were critically ill (i.e. located in an intensive care unit), encephalopathic, or had a history of cardiac arrhythmia were excluded from participating.

All subjects provided informed consent. The study was approved by the institutional ethical standards committee on human experimentation of the University of Michigan Health System.

We performed nerve conduction studies on all subjects using a Viking EDX Electrodiagnostic System (Natus Neurology Incorporated 3150 Pleasant View Road Middleton, WI 53562). Control subjects underwent nerve conduction studies in the electromyography lab. Subjects with central lines underwent nerve conduction studies in a patient room, the dialysis lab, or the inpatient infusion center.

The protocol consisted of 16 stimulations or sets of stimulations, for a total of 40 impulses, at the standard stimulation sites for the left and right ulnar nerves at the wrist and the left and right spinal accessory nerves at the neck. A ground electrode was placed on the upper extremity ipsilateral to the stimulations. At each stimulation site, we performed both single and 2-Hz repetitive stimulations (4 stimulations over 2 seconds) at both low and high voltages. Low voltage stimulation was defined as 100 mA with a 0.02 second duration. High voltage stimulation was defined as 100 mA with a 0.5 ms duration in the ulnar nerve and 100 mA with a 0.1 ms duration in the spinal accessory nerve. The duration of 0.1 ms was found to be sufficient to elicit a supramaximal spinal accessory compound muscle action potential in all control subjects. Therefore, to minimize discomfort, this duration was used in the subjects with central lines.

Throughout the study, each subject had 12-lead electrocardiogram (ECG) monitoring, with at least 10 seconds of continuous recording before and after each stimulation or set of stimulations. The paper ECG tracings were marked at the time of each stimulation. A board certified cardiologist reviewed all ECG

tracings with attention to cardiac conduction abnormalities or malignant arrhythmias, defined as 3 or more consecutive ectopic beats or a triplet.

Results

Ten control subject and 10 subjects with central venous catheters underwent the nerve conduction study protocol. The mean age of subjects with central lines was 44.6 yrs. The mean age of control subjects was 39.3 yrs. The mean body mass index of subjects with central lines was 25.6 (range 18.0 – 38.7). The mean body mass index of control subjects was 25.7 (range 17.8 – 33.6). Four study subjects had *Bard Power-Trialysis™* short term dialysis catheters inserted into the internal jugular vein with an exit site at the base of the neck. Six subjects had *Arrow Cannon Catheter II™* dialysis catheters inserted into the internal jugular vein with an exit site in the anterior chest wall. Nineteen of 20 subjects completed the entire study protocol. One subject requested that the procedure be aborted after 31 of the 40 stimulations because of discomfort.

During the nerve conduction protocol, no cardiac conduction abnormalities or malignant arrhythmias were noted in any of the study or control subjects. (Figure 1) Benign ectopic beats and atrial runs were noted incidentally in both study and control subjects. None of these correlated with the timing of the nerve conduction stimulations.

Discussion

Nerve conduction studies of the upper extremities, including ipsilateral stimulations, proximal stimulations, and low frequency repetitive stimulations do not appear to confer a risk of cardiac conduction abnormality or arrhythmia in the general population of patients with central venous catheters. Appropriately, the package inserts for the 2 catheters used in this study do not list exposure to exogenous electricity as a contraindication.[9] [10] Standard central venous catheters, such as those used in this study, are made out of polyurethane, an inert polymer that conducts electricity poorly. One of the theoretical risks of central lines is that leakage of intravenous fluid around the catheter insertion site could result in an electrolyte solution which would conduct electricity around the outside of the catheter. The results of this study should only be generalized to patients with central lines with dry insertion sites that are covered with a semi-permeable dressing.

Although the ground electrode was always placed on the ipsilateral arm, it has no actual role in patient safety. The ground electrode does not actually serve to direct stray charges away from the body, as is often taught. It is merely a reference point for the active and reference electrodes.[11]

Many individuals with central venous catheters are critically ill and require intensive medical care. A notable limitation of this study is that these patients and those with pre-existing cardiac arrhythmia were excluded. We felt that it was prudent to first demonstrate safety in the general population. Further studies are needed to determine if nerve conduction studies are equally safe in at-risk populations.

It is also unknown if proximal stimulations with durations of greater than 0.1 ms are safe, but we did not find a need to use longer stimulation durations to achieve a supramaximal compound muscular action potential response in our control population. We chose the spinal accessory nerve in the study protocol, because the stimulations were given in close proximity to the catheter insertion sites. The spinal accessory is also the most commonly studied proximal nerve in our laboratory. However, it is relatively superficial compared to the nerve bundles at the axilla and the Erb point. It is possible that higher stimulation durations than we studied would be necessary to achieve a supramaximal response from these other proximal stimulation sites.

With the class of central lines included in this study, the catheter tip is in the lower superior vena cava or right atrium. It is not clear if the results of this study can be generalized to patients with Swan-Ganz catheters, which extend through the right atrium, right ventricle, and into the pulmonary artery.

The number of subjects in this study was small, but 391 total stimulations to patients with central lines did not lead to deleterious effects on cardiac conduction. This, in conjunction with the fact that there has never been a reported case of a patient with a central line developing a nerve conduction study-induced arrhythmia, supports the safety of the procedure in the general population. It is important to recognize, however, that even a very small risk of a life-threatening complication would not be acceptable. A single case report of a patient with an iatrogenic arrhythmia could outweigh the findings of this study.

Figure **1: ECG** leads I and II from a study subject who had a central line in the internal jugular vein with an exit site at the base of the neck. The 4 arrows indicate the shock artifact from 2 Hz repetitive stimulation (100 mA and 0.1 ms) delivered at the standard stimulation site of the right spinal accessory motor nerve. No changes in cardiac rhythm are detected.

Abbreviations:

ECG – electrocardiogram

1. Starmer, C.F., H.D. McIntosh, and R.E. Whalen, *Electrical hazards and cardiovascular function.* N Engl J Med, 1971. **284**(4): p. 181-6.
2. Lee, W.R. and J.R. Scott, *Thresholds of fibrillating leakage currents along intracardiac catheters: an experimental study.* Cardiovasc Res, 1973. **7**(4): p. 495-500.
3. Schoeck, A.P., et al., *Safety of nerve conduction studies in patients with implanted cardiac devices.* Muscle Nerve, 2007. **35**(4): p. 521-4.
4. LaBan, M.M., et al., *Peripheral nerve conduction stimulation: its effect on cardiac pacemakers.* Arch Phys Med Rehabil, 1988. **69**(5): p. 358-62.
5. Cronin, E.M., et al., *Safety of repetitive nerve stimulation in patients with cardiac implantable electronic devices.* Muscle Nerve, 2013. **47**(6): p. 840-4.
6. Merkel, R. and M.D. Sovie, *Electrocution hazards with transvenous pacemaker electrodes.* Am J Nurs, 1968. **68**(12): p. 2560-3.
7. Mellion, M.L., et al., *Safety of nerve conduction studies in patients with peripheral intravenous lines.* Muscle Nerve, 2010. **42**(2): p. 189-91.
8. Al-Shekhlee, A., B.E. Shapiro, and D.C. Preston, *Iatrogenic complications and risks of nerve conduction studies and needle electromyography.* Muscle Nerve, 2003. **27**(5): p. 517-26.
9. *Power-Trialysis(TM) {package insert}. Bard Access Systems, Salt Lake City, UT.* [cited 2016 August 8]; Available from: http://www.bardaccess.com/assets/literature/0736073_Power-Trialysis_IFU_web.pdf.
10. *Cannon (TM) II Plus [package insert] Arrow International, Inc., Reading PA; 2014.*
11. Robinson, L.R., M. Christie, and S. Nandedkar, *A Message from the Ground Electrode.* Muscle Nerve, 2016.